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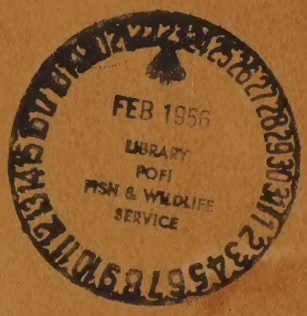

VOLUME VII

Sediment Cores from the North Atlantic Ocean

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GÖTEBORG
ELANDERS BOKTRYCKERI AKTIEBOLAG

REPORTS OF THE SWEDISH DEEP-SEA EXPEDITION. VOL. VII
SEDIMENT CORES FROM THE NORTH ATLANTIC OCEAN. NO. 2

ON THE GEOCHEMISTRY OF THE NORTH ATLANTIC SEDIMENT CORE NO. 238

BY

STURE LANDERGREN

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Introduction

Our knowledge of the geochemistry of deep sea sediments has hitherto been rather scanty, partly due to the difficulties concerned with the collection of bottom sediments in quantities sufficient for studies on the distribution of elements on a large scale.

During the Swedish Deep Sea-Expedition in the years 1947—1948 a very important sediment material became available for studies from different points of view thanks to the immense progress in the technique by using the piston coresampler worked out by B. KULLENBERG (1947). This technique makes it possible to take long cores of bottom sediments even from the deepest regions of the oceans, thus realizing closer studies i. a. on the distribution of elements in the deep-sea sediments.

In the present study a long core from the Atlantic has been spectrochemically analysed. The core is No 238 of the collection of the »Albatross» expedition (Albatross station No 339). The position of the core is Lat S 00° 07′, Long W 18° 12′. Depth: 7 315 m. Length of the core: 14.12 m. Thus, the sediment emanates from the depression called the »Romanche» deep. From this core samples are taken on each dm from the top of the core. Thus, 141 samples have been analysed. The contents of the following elements have been determined, namely magnesium, aluminium, calcium, titanium, vanadium, chromium, manganese, iron, cobalt, and nickel.

Dr. O. MELLIS has studied the mineralogical composition of the core and he has i. a. determined the grain size of the core 238 (1953). By the courtesy of Dr. MELLIS his results were

placed at my disposal so that the relationship between the grain size and the distribution of the elements could be studied.

The samples from the core have kindly been placed at my disposal by professor HANS PETTERSSON, leader of the Swedish Deep-Sea Expedition mentioned.

Analytical Methods

The spectrochemical technique employed in this investigation for the determination of the major and minor constituents mentioned above is a combination of chemical and spectrochemical operations worked out in the geochemical laboratory of the geological survey of Sweden. A forthcoming report of the methods will be published later. The reproducibility of the results is ± 2 to 5 per cent of the contents of the elements determined, with exception of calcium for which the accuracy is estimated at about ± 10 per cent for concentrations up to 10 per cent. Contents greater than 10 per cent are estimated.

In order to find a quantitative expression of the relationship between the quantities here dealt with the product-moment coefficients of correlation have been calculated.

The analytical results are presented in Tables 1—7 and on diagrams in Figs 1—4.

The Distribution of the Major Constituents

The major constituents which will be discussed are aluminium, magnesium, calcium, and iron. The content of Al is significant for the hydrolyzate sediments, magnesium and iron for the amount of dark minerals included in the sediment, and the bulk of the content of calcium represents material derived from organic matter, especially from foraminifera. In addition, iron is the major element of the ferride group the distribution of which will be discussed later.

In Table 1 the analytical results for magnesium, aluminium, and calcium are presented. Table 2 gives a survey of the content of the major constituents in different milieus. The content of iron — together with the other ferrides — is found in Table 3.

In Figs 1—3 are presented diagrams showing the distribution of some of the quantities here discussed and in Fig 4 the relative rate of accumulation of Al, Ca, Ti, and Mn is illustrated.

Aluminium

As seen from Table 1 the content of this element varies through the core. Fig. 1 demonstrates, on the other hand, that the distribution is fairly uniform within certain parts of the core, but the difference in the average contents of these parts is remarkable. On the basis of the distribution of aluminium, the criterion of the amount of hydrolyzate, the core may be subdivided into four parts, namely 10—320, 330—690, 700—800, and 810—1 411 cms from the top of the core. I will show later that this subdivision has a real chemical sense, quite apart from stratigraphical considerations.

The average content of Al is 4,67 per cent. This content is too low to be significant for a pure hydrolyzate sediment where the average content is 8,19 per cent. The igneous rocks contain 8.13 per cent on an average. As seen from Table 2 only those parts of the core at 10—320 and 700—800 cms have average contents approaching that of the hydrolyzates.

The cause of the decrease in aluminium is obviously a »dilution» of the minerogene component with carbonate derived from organic matter. The content of Al is consequently depending on the addition of carbonates — mainly calcite — during the settling of the sediment. Most investigators therefore make a correction for the amount of calcite when discussing the content of the minerogene

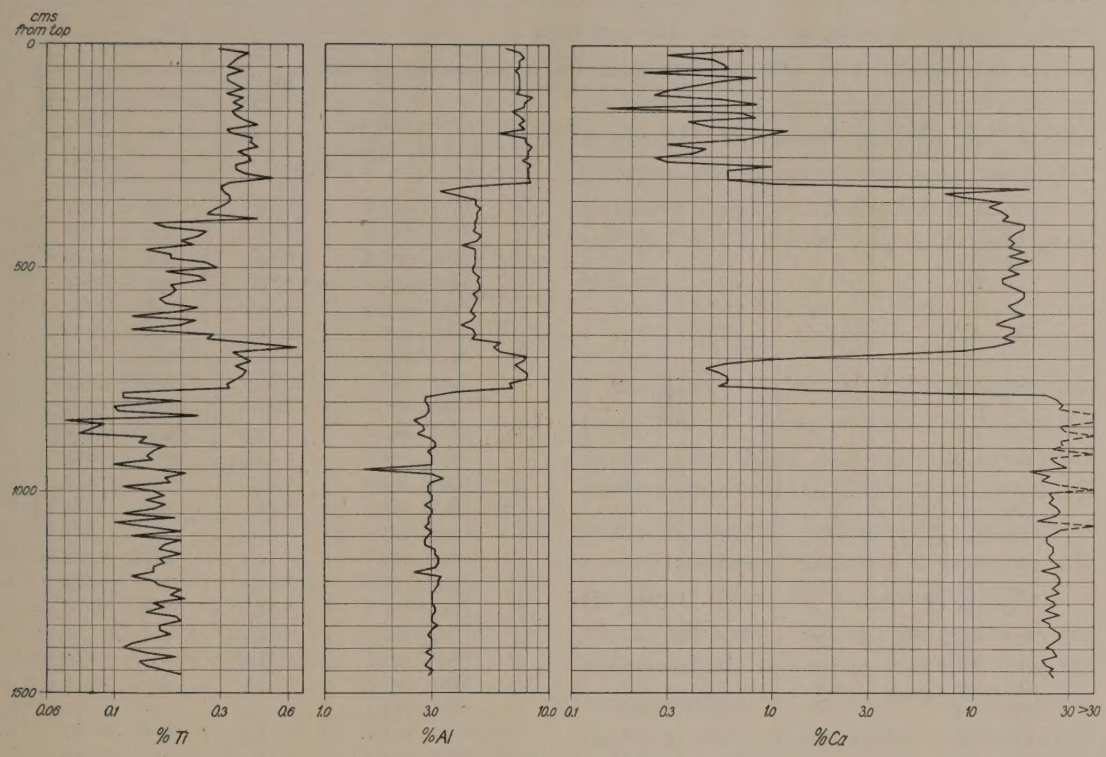

Fig. 1. Diagrams of the distribution of titanium, aluminium, and calcium in core 238. The contents are in per cent of weight on a logarithmic scale.

elements. Objections can be raised to this method of correction, since the amount of calcite in a marine sediment is strongly affected by the pH-conditions of the surroundings, the CO_2 pressure, and temperature. In this study an other method is used, based on the presumption that the content of Al in the hydrolyzates is almost constant and independent of the chemical composition of the igneous rocks, the primary source of the minerogene component. A probable average content of aluminium in the hydrolyzates is 8 per cent Al. An estimate of the content of hydrolyzate(= the minerogene part) in the core gives the following results:

Level	Content of Al	Percentage content of hydrolyzate
10—320 cms	7.65	96
330—690 »	4.74	59
700—800 »	7.50	94
810—1411 »	2.95	37
average	4.67	58

Clearly the content of SiO_2 derived from organic matter might also be considered but this content may be of minor importance in this case.

Magnesium

Table 1 gives the content of Mg in the samples analysed. The distribution of this element is more irregular than that of aluminium, as demonstrated in Fig. 2, but also in this case — less pronounced, however — one finds a tendency in the distribution of Mg which supports such a subdivision of the core as discussed before.

The average content of Mg is about 2 per cent. The averages for the different parts of the core are found in Table 2. The igneous rocks contain 2.09 per cent on an average and the hydrolyzates 1.48 per cent. A correction of the content of Mg with regard to the content of hydrolyzate in the sediment is

TABLE 1

The Content of Magnesium, Aluminum, and Calcium

Level from the top of the core (in cms)	Mg	Al	Ca
10—11.5	1.7	6.5	0.72
20—21.5	1.8	7.4	0.30
28—29.5	1.7	7.8	0.50
40—41.5	2.9	7.4	0.56
50—51.5	2.2	7.4	0.59
60—61.5	1.7	7.1	0.23
70—71.5	2.1	7.4	0.83
80—81.5	2.0	7.4	0.56
90—91.5	—	—	—
100—101.5	1.9	7.4	0.30
109—110.5	1.7	7.2	0.26
120—121.5	2.1	8.5	0.56
130—131.5	2.1	7.9	0.83
140—141.5	1.8	7.8	0.15
150—151.5	2.1	6.9	0.70
160—161.5	2.3	7.4	0.83
170—171.5	1.9	7.8	0.38
181—182.5	2.2	7.4	0.47
190—191.5	3.2	7.8	1.20
200—201.5	6.7	6.0	0.91
210—211.5	1.7	7.8	0.72
220—221.5	1.6	7.9	0.30
230—231.5	1.9	8.4	0.47
240—241.5	2.3	8.1	0.41
250—251.5	1.4	8.1	0.26
260—261.5	1.5	7.7	0.30
270—271.5	1.8	8.3	1.00
280—281.5	1.7	8.1	0.60
292—293.5	1.6	8.1	0.60
300—301.5	1.7	8.1	0.60
310—311.5	3.4	8.3	1.10
320—321.5	1.0	4.3	19
330—331.5	1.5	3.3	7.30
340—341.5	1.0	—	9.10
351.5—353	3.1	4.7	14
360—361.5	2.5	4.7	12
370—371.5	2.5	5.0	14
380—381.5	3.5	4.8	15
390—391.5	3.3	4.8	14
400—401.5	4.2	4.7	18
410—411.5	4.0	4.7	18
420.5—422	4.4	4.6	16
430—431.5	3.8	5.0	15
440—441.5	3.4	4.8	16
450—451.5	3.6	4.1	15
460—461.5	4.2	4.7	18
470—471.5	2.9	4.7	15
480—481.5	3.1	4.7	19
490—491.5	4.6	4.7	16
500—501.5	3.6	4.6	15
510—511.5	3.2	4.6	17
520—521.5	3.2	4.9	14
530—531.5	3.6	4.8	14
540—541.5	2.9	4.9	16
550—551.5	4.2	4.9	18
560—561.5	4.3	4.6	18
570—571.5	3.1	4.8	17
580—581.5	3.3	4.7	15
590—591.5	2.5	4.6	16
600—601.5	3.1	4.5	18
610—611.5	4.5	4.7	15
620—621.5	2.5	4.5	13
630—631.5	3.3	4.1	16
640—641.5	4.8	4.6	16
650—651.5	3.0	4.7	14
660—661.5	3.6	4.5	16
670—671.5	5.3	6.1	13
680—681.5	5.0	5.7	8.9
690—691.5	2.2	6.1	3.1
700—701.5	1.8	7.9	1.1
710—711.5	1.4	7.8	0.60
720—721.5	1.1	7.1	0.47
730—731.5	1.6	7.6	0.54
740—741.5	1.8	8.1	0.60
750—751.5	1.6	8.0	0.60
760—761.5	2.0	6.7	0.54
770—771.5	1.6	6.9	1.5
780—781.5	1.2	3.7	23
790—791.5	0.9	2.8	26
800—801.5	1.4	2.8	28
810—811.5	0.9	2.9	27
819.5—821	1.4	2.9	> 30
830—831.5	1.3	2.8	> 30
840—841.5	1.2	2.5	> 30
850.5—852	0.9	2.7	27
860—861.5	0.9	2.8	29
870—871.5	0.8	2.6	> 30
880—881.5	1.0	2.9	27
888.5—890	1.0	3.1	28
900—901.5	1.1	3.1	25
910—911.5	1.3	2.9	> 30
920—921.5	1.3	3.0	24
930—931.5	1.5	3.0	26
940—941.5	1.3	3.0	29
950—951.5	1.2	1.5	19
959.5—961	1.1	3.0	24
970—971.5	0.9	3.4	22
980—981.5	1.3	3.0	27
990—991.5	1.5	2.9	> 30
1000—1001.5	1.3	2.9	24
1010—1011.5	1.3	3.0	25
1020—1021.5	0.9	3.0	24
1030—1031.5	1.2	2.8	26
1040—1041.5	1.0	3.0	27
1050—1051.5	1.4	3.0	26
1060—1061.5	1.2	2.9	21
1070—1071.5	1.3	2.9	> 30
1080—1081.5	1.0	2.8	27
1090—1091.5	1.3	3.0	25
1100—1101.5	1.1	2.9	23
1110—1111.5	1.2	2.8	23
1120—1121.5	1.1	2.8	25

TABLE 1 (continued)

Level from the top of the core (in cms)	Mg	Al	Ca
1130—1131.5	1.1	3.1	25
1140—1141.5	1.2	3.1	24
1150—1151.5	1.0	3.2	25
1160—1161.5	1.1	3.2	27
1170—1171.5	1.0	3.1	22
1180—1181.5	0.9	2.5	26
1190—1191.5	1.0	3.3	27
1200—1201.5	1.2	3.2	27
1210—1211.5	1.2	3.2	25
1220—1221.5	1.0	3.1	27
1230—1231.5	1.1	3.0	23
1240—1241.5	1.4	3.0	25
1250—1251.5	1.2	3.0	26
1260—1261.5	1.0	3.1	23
1270—1271.5	1.2	3.1	27
1280—1281.5	1.1	3.0	22
1290—1291.5	1.4	3.0	24
1300—1301.5	1.2	3.2	24
1310—1311.5	1.3	3.0	27
1320—1321.5	1.1	2.9	27
1330—1331.5	1.0	3.0	25
1340—1341.5	0.8	3.0	23
1350—1351.5	1.0	3.0	25
1360—1361.5	1.2	2.8	26
1370—1371.5	1.3	3.0	22
1380—1381.5	1.1	2.9	23
1391—1392.5	0.9	2.8	25
1400—1401.5	1.1	3.0	24
1410—1411.5	1.1	2.9	25
Average	1.97	4.67	—

TABLE 2

The Distribution of the Major Constituents

	Al	Fe	Mg	Ca
Igneous rocks	8.13	5.0	2.09	3.63
Sediments:				
Resistates	2.53	1.0	0.71	3.95
Hydrolyzates	8.19	4.73	1.48	2.23
Precipitates	0.43	0.40	4.77	30.45
Core 238:				
10— 320 cms	7.65	3.9	2.1	0.6
330— 690 »	4.74	3.7	3.6	15
700— 800 »	7.50	3.2	1.5	0.75
810—1411 »	2.95	1.9	1.1	25
Average:	4.67	2.95	1.97	16

useless for two reasons. A correction presupposes, namely, that the bulk of this element is of minerogene origin and thus a constituent of the hydrolyzate. This is probably not the case. One part of magnesium may be derived from the sea water as an accidental constituent. Another part is deposited as carbonate. It is probable, however, that the real content of Mg in the hydrolyzate is higher than that presented in Table 2. Anyhow, that part of the core at 320—690 cms has the highest content.

Calcium

The bulk of the major constituents discussed is of minerogene origin. Calcium, on the other hand, is only to a small part derived from rock material. This element is deposited mainly through the activity of organic processes occurring in the sea. As mentioned before the amount of calcium in a marine sediment is strongly influenced by the pH-conditions, the pressure of CO_2, and the temperature of the surrounding water. Thus, the element takes part in the carbon dioxide cycle of the sea and the deposition of calcite can be regarded as a link in this cycle, independant of the primary source of calcium.

The content of Ca is presented in Table 1. In Table 2 the averages from the different parts of the core are found. The diagram in Fig. 2 illustrates the distribution. One finds that the differences in the average contents of the different parts of the core is appreciable. In the uppermost part the content is rather low with an average of 0.6 per cent Ca and the range of distribution between 0.15—1.20 per cent. In the second part the content increases by more than an order of magnitude, with an average of about 15 per cent. In this part, however, the amount of Ca is rather uniform. In the third part the content decreases to an average of 0.75 per cent. In the lowest part of the core the content again rises to about 25 per cent. This content corresponds to an amount of $CaCO_3$ of 79 per cent.

A comparison between the diagrams of Ca and Al is interesting (Fig. 1). It is evident that the contents of the two elements are

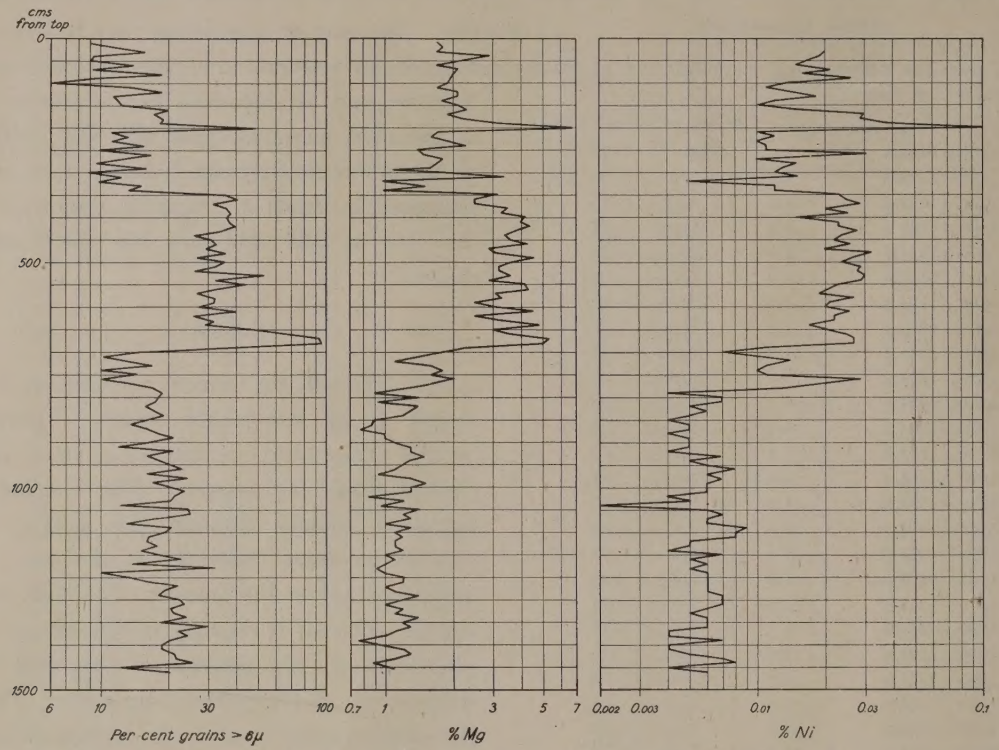

Fig. 2. Diagrams of the distribution of grain size, magnesium, and nickel in core 238. In the diagram of the grain size the abscissa represents the percentage amount of grains with a size $> 6\,\mu$. The contents of magnesium and nickel are in per cent of weight.

antibatic and almost inversely proportional. This feature is easily understood, if one regards the sediment of the core as a mixture of mainly two components — hydrolyzate and calcite — derived from different sources.

Iron

The contents of iron in the samples are set out in Table 3, and the averages of the different parts of the core are presented in Table 4. As seen from the diagram in Fig. 3 the amount of iron varies considerably throughout the core. No decided differences in the averages for the three uppermost parts of the core exists. Only a slight tendency towards decreasing content of iron in the lowest part of the core is observed, as seen from Table 3. A correction of the figures for the Al content gives the following result:

Level	per cent iron	corrected figures
10—310 cms	3.9	4.1
320—690 »	3.7	6.3
700—800 »	3.2	3.4
810—1411 »	1.9	5.1
Average	2.95	5.1

The corrected figures correspond reasonably with what can be expected for a marine hydrolyzate derived from basic rock members. The average content of iron in the hydrolyzates is 4.7 per cent. The corrected content is also in reasonable agreement with the average content in red clay from the Pacific, as seen from Table 4.

Iron and magnesium enter the structures of the dark rock-forming minerals where they can replace each other diadochically. Iron is further the most abundant element in the ore minerals occurring in the sediment (magnetite,

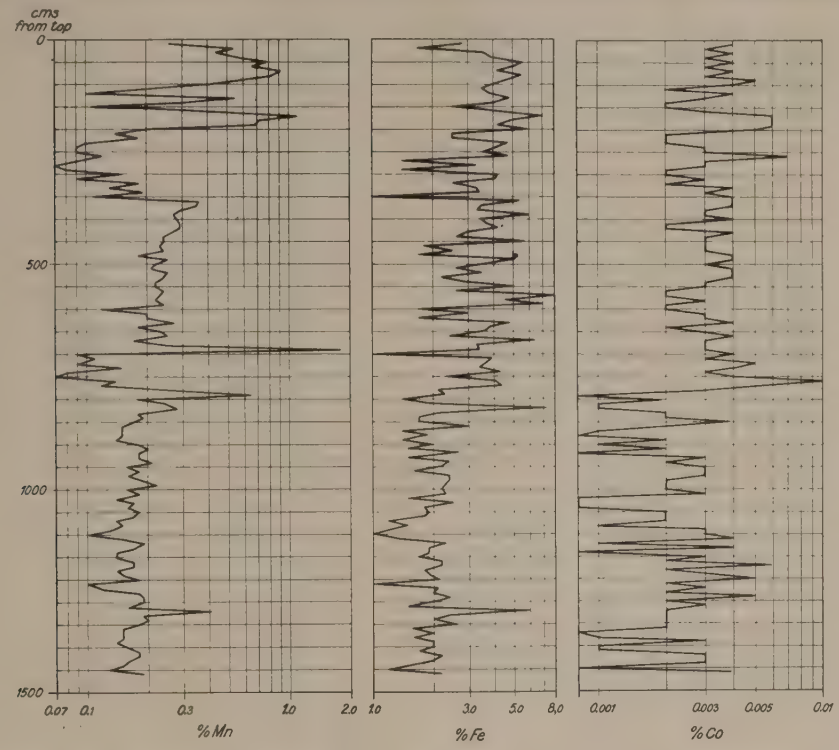

Fig. 3. Diagrams of the distribution of manganese, iron, and cobalt in core 238. The contents are in per cent of weight.

ilmenite, hematite etc). The element is also the most abundant member of the ferride group and the other ferrides are referred to the content of iron.

Thus, aluminium, calcium, magnesium, and iron are regarded as reference elements each representing different components of the sediment of the core investigated.

The Distribution of the Ferrides

Titanium, vanadium, chromium, manganese, iron, cobalt, and nickel form a coherent group of transitional elements for which the collective term *the ferrides* is proposed (LANDERGREN, 1943). These elements always occur together in Nature. However, the chemical differentiation within this group of elements is strong enough so that differences in the geological conditions prevailing during the deposition affect differences in the relative abundance of the ferrides.

The contents of the ferrides are presented in Table 3. In Table 4 a survey of the contents of the ferrides in the different parts of the core and in different milieus is given. In Table 5 the contents of the ferrides are recalculated with iron as reference element.

In Figs 1—3 diagrams of the distribution of Ti, Mn, Fe, Co, and Ni are set out.

Also when dealing with the contents of the ferrides it is necessary to make corrections of some kind. If we presume that the bulk of the ferrides emanate from the hydrolyzate component, a similar correction can be made as for the major constituents (described in connection with aluminium). However, in some cases one is in doubt whether or not this presumption holds good, viz. that all ferrides emanate from the same source. Anyhow, when comparing the distribution of the ferrides in the core sediment with that of other milieus it is advisable also to recalculate the contents of the ferrides as atom per cent of iron. This

TABLE 3

The Content of the Ferrides (in ppm)

Level from the top of the core in cms	Ti	V	Cr	Mn	Fe	Co	Ni
10—11.5	2900	40	40	2600	28000	40	200
20—21.5	4000	30	40	5300	17000	30	200
28—29.5	3600	40	70	4400	36000	40	200
40—41.5	3400	30	70	5500	39000	30	190
50—51.5	3200	40	40	7800	55000	40	170
60—61.5	3800	40	50	6600	51000	30	150
70—71.5	3200	40	60	9100	42000	40	210
80—81.5	3200	20	40	8200	55000	30	160
90—91.5		20	60			50	260
100—101.5	3800	40	70	3900	39000	40	140
109—101.5	3200	50	60	1900	35000	20	110
120—121.5	3800	40	70	1000	38000	40	140
130—131.5	3400	10	50	5400	48000	30	180
140—141.5	3800	30	50	3000	41000	20	120
150—151.5	3400	10	40	1000	25000	20	100
160—161.5	3500	40	30	3500	43000	30	150
170—171.5	3800	30	60	11000	69000	60	300
181—182.5	4400	<10	50	7200	49000	60	290
190—191.5	3200	20	90	6800	42000	60	380
200—201.5	3400	10	200	2000	58000	50	990
210—211.5	4200	20	50	1400	25000	20	100
220—221.5	4100	20	30	1800	25000	20	120
230—231.5	4400	<10	60	1000	47000	20	100
240—241.5	3600	50	50	900	42000	30	110
250—251.5	4000	10	40	900	36000	30	110
260—261.5	4100	20	30	1200	47000	70	310
270—271.5	3500	<10	40	900	14000	30	100
280—281.5	3500	60	60	700	33000	30	150
292—293.5	3900	30	60	800	14000	20	130
300—301.5	5100	20	50	1500	42000	20	120
310—311.5	3300	<10	60	900	41000	30	150
320—321.5	3000	<10	10	1800	25000	20	50
330—331.5	3100	10	50	1300	33000	40	120
340—341.5	3300	<10	20	1900	34000	30	120
351.5—353	3300	<10	50	1100	10000	40	230
360—361.5	3100	<10	50	3600	54000	40	250
370—371.5	2800	20	20	3500	35000	40	290
380—381.5	2600	20	70	2900	33000	30	200
390—391.5	4400	<10	40	2700	61000	30	250
400—401.5	1500	<10	30	2800	34000	40	170
410—411.5	1700	<10	40	2900	37000	20	230
420.5—422	2600	10	40	2900	42000	20	230
430—431.5	2400	<10	30	2600	29000	40	280
440—441.5	2000	<10	40	2400	26000	30	240
450—451.5	2300	10	30	2400	56000	30	220
460—461.5	1400	<10	70	2300	28000	30	260
470—471.5	1800	20	40	2400	25000	30	220
480—481.5	1800	20	40	1800	17000	40	320
490—491.5	2600	<10	50	2500	51000	40	270
500—501.5	2900	10	60	2200	34000	30	240
510—511.5	1700	20	50	2100	26000	40	290
520—521.5	2400	<10	60	2500	35000	40	280
530—531.5	2600	<10	50	2400	22000	40	300
540—541.5	1800	<10	60	2200	29000	30	290
550—551.5	1900	<10	50	2200	51000	30	230
560—561.5	1800	<10	40	2400	36000	20	210
570—571.5	1600	<10	40	2300	79000	20	190
580—581.5	1700	<10	60	2200	45000	30	270
590—591.5	2400	20	70	2400	69000	20	210
600—601.5	1900	40	30	1200	17000	20	200
610—611.5	1200	20	40	2000	30000	30	260
620—621.5	2300	30	70	2000	17000	30	220
630—631.5	2000	<10	40	2700	48000	40	220
640—641.5	1200	20	60	1800	38000	20	170
650—651.5	2800	<10	60	2300	36000	30	200
660—661.5	2600	20	50	2500	24000	40	250
670—671.5	4300	20	100	1700	64000	30	270
680—681.5	6600	80	200	2500	33000	30	270
690—691.5	3400	<10	30	18000	34000	30	110
700—701.5	3700	<10	20	900	10000	40	70
710—711.5	4100	30	20	1100	39000	30	100
720—721.5	3500	20	30	900	37000	50	140
730—731.5	3900	20	30	1500	34000	40	110
740—741.5	3800	10	40	800	43000	30	100
750—751.5	3500	30	40	700	23000	40	110
760—761.5	3200	10	40	1400	41000	100	290
770—771.5	3300	20	50	1200	44000	50	200
780—781.5	1100	<10	20	2900	21000	30	130
790—791.5	1100	<10	10	6500	23000	<10	40
800—801.5	2000	<10	10	1800	14000	20	70
810—811.5	1000	<10	20	2500	19000	10	70
819.5—821	1100	<10	40	2800	74000	10	50
830—831.5	2400	<10	20	1800	22000	20	60
840—841.5	600	<10	40	1900	17000	20	50
850.5—852	900	<10	30	1700	17000	40	40
860—861.5	800	<10	40	1500	30000	20	50
870—871.5	700	<10	20	1500	14000	10	50
880—881.5	1400	<10	10	1500	19000	<10	40
888.5—890	1300	<10	20	1400	14000	20	50
900—901.5	1700	<10	10	1800	19000	10	50
910—911.5	1500	<10	20	2000	15000	20	50
920—921.5	1400	<10	10	1800	27000	<10	40
930—931.5	1500	<10	10	1800	15000	30	70
940—941.5	1000	<10	10	2100	24000	20	50
950—951.5	1500	<10	20	1600	22000	30	60
959.5—961	2100	<10	30	1800	16000	30	80
970—971.5	1700	<10	30	1600	24000	30	60
980—981.5	1800	<10	40	1900	24000	20	70
990—991.5	1100	<10	30	2200	23000	20	60
1000—1001.5	1500	<10	40	1600	22000	20	60
1010—1011.5	1700	<10	20	1800	23000	30	60
1020—1021.5	1400	<10	10	1400	15000	<10	40
1030—1031.5	1700	<10	30	1700	25000	<10	50
1040—1041.5	1500	20	10	1600	18000	<10	20
1050—1051.5	1100	<10	10	1800	19000	20	60
1060—1061.5	1900	<10	10	1700	18000	20	70
1070—1071.5	1000	<10	30	1400	12000	20	60
1080—1081.5	1600	<10	30	1500	15000	10	60
1090—1091.5	2000	<10	20	1300	12000	30	90
1100—1101.5	1200	<10	10	1000	10000	30	80

TABLE 3 (continued)

Level from the top of the core in cms	Ti	V	Cr	Mn	Fe	Co	Ni
1110—1111.5	2000	<10	10	1500	14000	40	80
1120—1121.5	1700	<10	10	1900	23000	10	50
1130—1131.5	1600	<10	20	1700	19000	40	50
1140—1141.5	2000	<10	20	1400	19000	10	40
1150—1151.5	1600	<10	10	1400	17000	30	70
1160—1161.5	1700	<10	10	1700	22000	20	50
1170—1171.5	1500	<10	20	1700	22000	60	60
1180—1181.5	1500	<10	20	1400	18000	20	50
1190—1191.5	1200	<10	20	1500	19000	30	60
1200—1201.5	1500	<10	10	1800	21000	50	60
1210—1211.5	1600	40	20	1000	10000	20	60
1220—1221.5	2000	<10	40	1200	21000	30	60
1230—1231.5	1800		20	1800	20000	20	60
1240—1241.5	2100	<10	10	1900	24000	50	70
1250—1251.5	1500	<10	10	1900	20000	20	70
1260—1261.5	1700	<10	10	1600	15000	30	70
1270—1271.5	1400	<10	10	4100	61000	20	60
1280—1281.5	1900	<10	10	1900	25000	20	50
1290—1291.5	2000	<10	10	2000	20000	20	60
1300—1301.5	1600	<10	10	1800	26000	20	60
1310—1311.5	1600	<10	10	1500	16000	20	60
1320—1321.5	1800	<10	10	1500	20000	<10	40
1330—1331.5	1500	<10	10	1500	16000	<10	40
1340—1341.5	1200	<10	10	1400	20000	30	70
1350—1351.5	1100	<10	10	1600	20000	10	40
1360—1361.5	1400	<10	10	1800	17000	10	40
1370—1371.5	1900	<10	10	1800	22000	30	50
1380—1381.5	1300	<10	10	1600	20000	30	70
1391—1392.5	1400	<10	10	1500	16000	30	80
1400—1401.5	1700	<10	30	1300	12000	<10	40
1410—1411.5	2000	<10	30	1900	22000	40	60

operation makes comparisons possible. In Table 5 the ferrides are recalculated as mentioned.

A brief description of the particular ferrides is given below.

Titanium

The average content of the core is 2 400 ppm Ti. This is the same average content as that found in the sediments from the Atlantic collected during the »Meteor» expedition in 1925—1927 (CORRENS, 1937). It is likely that these figures can be directly compared. The amount of Ti in the sediments from the Tyrrhenian sea is a little lower (about 2000 ppm) than that of the core. The red clay of the Pacific is much higher, due i. a. to the higher content of Fe in this sediment, as seen from Table 5.

The averages for the different parts of the core vary a little. A correction for the hydrolyzate component gives the following figures:

Level	ppm Ti	corrected content
10—320 cms	3700	3900
330—690 »	2500	4200
700—800 »	3000	3200
810—1411 »	1500	4100
Average	2400	4100

TABLE 4

The Contents of the Ferrides (in ppm)

	Ti	V	Cr	Mn	Fe	Co	Ni
Igneous rocks (average)	4400	150	200	1000	50000	23	80
Sediments:							
Resistates (average)	960	20	68—200	trace	9900	0	2—8
Hydrolyzates (average)	4300	120	410—680	620	47300	8	24
Precipitates (average)	—	10	2	385	4000	0	0
»Meteor» Expedition	2400	—	—	1600	25900	—	—
Cores 13, 15, and 16 from the Tyrrhenian Sea (average)	1980	136	38	1300	60500	27	39
Cores 69, 70, 71, 72, 73, 77, 83, 85 from the red clay of the Pacific, average	7470	48	51	9430	56300	89	164
Core 238:							
10—320 cms	3700	26	51	3600	39000	34	170
330—690 »	2500	13	52	2700	37000	32	230
700—800 »	3000	15	28	1800	32000	34	120
810—1411 »	1500	6	18	1700	19000	22	60
Average of the core	2400	13	36	2400	29500	28	138
200—201.5 cms	3400	10	200	2000	58000	50	990

The corrected content is in rather good agreement with the average content of Ti in the igneous rocks (4 400 ppm) and the hydrolyzates (4 300).

A study of the ratio Ti/Fe with the aid of Table 5 is interesting. Thus, the ratio of the igneous rocks (average), the resistates, the hydrolyzates, the »Meteor» sediments, and the core (average) is rather similar. This feature illustrates the very close relationship between titanium and iron in the sedimentary processes. The igneous rocks, on the other hand show considerable variations in the ratio Ti/Fe. In the stony meteorites the ratio is 1.6 but in the peridotites, which have a chemical composition similar to that of stony meteorites, the ratio is considered to be as high as 16.1. This figure may refer to peridotites very poor in iron. The gabbros have a ratio of 6.5 and the basalts about 5 (similar to that in the red clay). Thus, the variations in the hydrolyzates may partly be due to variations in the rock material from which they emanate. It is of interest to note that in those parts of the core where the content of aluminium is highest, the ratio Ti/Fe has increased to above the average for the core. Fig. 1 illustrates the distribution of titanium through the core. Apart from irregularities in the distribution if titanium in detail there is an obvious similarity between titanium and aluminium (the second diagram in Fig. 1), indicating a rather strong relationship during deposition in the deep sea region here dealt with. The survey given below is intended to illustrate the relationship between titanium on the one hand and aluminium and iron respectively on the other. The contents are in weight per cent.

	Igneous rocks avg	Hydrolyzates avg	Core 238 (corrected)
Al	8.13	8.19	8.0
Ti	0.44	0.43	0.41
100 Ti/Al ..	5.4	5.3	5.1
Ti/Fe	10.3	10.6	9.4

The relationship between titanium and aluminium is as strong as that between titanium and iron.

Vanadium

According to JOST (1932) the average content of vanadium in marine clay sediments is 140 ppm. The igneous rocks contain about 150 ppm, according to V. M. GOLDSCHMIDT (1938). The sediment from the Tyrrhenian Sea has an average content of V estimated to 140 ppm (LANDERGREN, 1948) in good agreement with the average estimated by JOST. The average for the hydrolyzates is estimated to be 120 ppm. The average for the core is only 13 ppm (uncorrected) and that for the red clay (471 analyses) is 48 ppm. The corrected figures for the core are the following:

Level	The content analysed	Corrected content
10—320 cms	26	27
330—690 »	13	22
700—800 »	15	16
810—1411 »	6	16
Avergae	13	22

Thus, the decrease in the content of vanadium in the core cannot solely be accounted for by the dilution of the hydrolyzate component. In addition, the red clay shows a similar trend. Actually, the bulk of vanadium carried to the sea settles on the shelf, where the content of vanadium can reach appreciable amounts under favourable conditions. Also in the oxidates the content of vanadium can become rather high i. a. in marine oolitic iron ores (LANDERGREN, 1948).

The biophile tendency of vanadium is well known, i. a. due to investigations by I. and W. NODDACK (1940). Thus recent sea animals are able to accumalate vanadium in some cases by a factor 10^4 in relation to the content of V in sea water (estimated to about 0.003 ppm). However, the biophile tendency of this element should not be overemphasized.

TABLE 5

A Survey of the Distribution of the Ferrides in different Milieus

(The figures express number of ferride atoms in per cent of iron atoms)

	Ti	V	Cr	Mn	Co	Ni	Co : Ni
Meteorites:							
Iron	0.013	0.008	0.035	0.034	0.60	8.92	0.07
Stony	1.61	0.42	3.22	2.03	0.29	2.42	0.12
Troilites	—	—	1.76	0.83	0.15	1.56	0.10
Igneous rocks:							
Peridotites	16.09	—	5.79	2.26	0.36	4.68	0.08
Gabbros	6.49	0.06	0.42	1.38	0.086	0.17	0.51
Average	10.26	0.33	0.54	2.03	0.066	0.19	0.35
Sediments: (Avg)							
Resistates	11.3	0.22	0.74—2.2	tr	tr	0.02—0.08	—
Hydrolyzates	10.6	0.28	0.93—1.5	1.33	0.02	0.06	0.33
Precipitates	—	<0.3	0.054	9.76	—	—	—
Tyrrhenian Sea (avg)	3.82	0.25	0.067	2.18	0.042	0.061	0.67
Atlantic:							
»Meteor» sediments (avg)	10.81	—	—	6.28	—	—	—
Core 238: Level (cms)							
10—320	11.07	0.073	0.14	9.39	0.082	0.42	0.20
330—690	7.87	0.038	0.15	7.41	0.081	0.59	0.14
700—800	11.65	0.055	0.10	6.09	0.1	0.38	0.26
810—1411	8.33	0.031	0.09	8.24	0.095	0.28	0.34
200—201.5	6.83	0.019	0.37	3.51	0.081	1.63	0.05
Average	9.43	0.048	0.13	8.23	0.092	0.45	0.20
Pacific:							
Rec clay (avg)	5.09	0.10	0.05	17.77	0.16	0.26	0.62

Organic processes cannot solely be accounted for neither by the enrichment in certain shelf sediments nor by the deficiency in the deep sea sediments. It is likely that vanadium is deposited under favourable pH conditions in reducing milieus. Such conditions occur on the shelf but not in the deep sea regions. This may be the cause of the difference in the content of vanadium between the shelf sediments and the deep sea sediments. The minute amount of vanadium in the deep sea sediments hitherto investigated may be of minerogene origin. Actually, the ratio V/Fe in the core sediment is about the same as that of basic igneous rocks (Gabbros), but much lower than that of the hydrolyzate sediments in general, as seen from Table 5. This feature supports the idea that vanadium in the deep sea sediments investigated is derived mainly from basic igneous rocks.

Chromium

A survey of the content of Cr in the core is given below.

Level	ppm Cr (uncorr.)	ppm Cr (corrected)
10—320 cms	51	53
330—690 »	52	80
700—800 »	28	30
810—1411 »	18	49
200—201.5 »	200	270
Average	36	62

The average content of Cr in the core is of the same magnitude as that reported for

the sediments of the Tyrrhenian Sea and, too, the red clay of the Pacific, as seen from Table 5. Only some few samples analysed have contents which are notably higher than the average content, i. a. the thin layer of a comparatively coarsegrained sediment at 200—201.5 cms. Two other samples at 670 and 680 cms have contents of Cr which are 100 and 200 ppm respectively. In this connection it may be mentioned that of 473 samples of red clay from the Pacific hitherto analysed only about 8 per cent have contents of Cr which exceed 100 ppm or more.

The average content of Cr in the igneous rocks is estimated at 200 ppm (GOLDSCHMIDT) and 530 ppm (HEVESY, MERKEL, and WÜRSTLIN). LUNDEGÅRDH (1946) reports a value of 35 ppm for igneous rocks mainly from Sweden. In the light of the attempts cited above to present an average for chromium one can readily share the opinion of RANKAMA and SAHAMA (1950) that »the abundance of chromium in the upper lithosphere is still unsettled».

The abundance of Cr in resistate and hydrolyzate sediments is notable. In the precipitates, on the other hand, chromium is relatively scarce.

Chromium, ferric iron, and aluminium behave rather similarly in the exogene processes, due to similar chemical properties. In the resistates chromium mainly occurs in the resistent minerals chromite, magnetite and ilmenite. In the hydrolyzates, on the other hand, this element emanates from the magnesium-iron rock minerals (pyroxenes, amphiboles etc). In fact, a considerable part of the chromium content of the basic igneous rocks is bound in the silicates. Thus, it is likely that chromium and iron are symbatic in the resistate sediments. In the hydrolyzates chromium is symbatic with ferric iron, aluminium, and magnesium. The distribution of this element may, therefore, in many cases become very irregular in the hydrolyzates and this feature is confirmed by several investigations.

To illustrate the relationship mentioned above between chromium on the one hand and iron, aluminium, and magnesium on the other in the core sediment, the ratios Cr/Fe, Cr/Al, and Cr/Mg for the different parts of the core are presented below.

Level	100Cr/Fe	100Cr/Al	100Cr/Mg
10—310 cms	0.14	0.07	0.24
320 690 »	0.15	0.11	0.14
700 -800 »	0.10	0.04	0.18
810—1411 »	0.09	0.06	0.16
200—201.5 »	0.37	0.33	0.30

The ratio Cr/Fe has decreased considerably compared with hydrolyzate sediments. Only in the coarse-grained layer at 200 cms the ratio approaches that of basic igneous rocks, as seen from Table 5. The survey above indicates that the relationship between chromium and magnesium is at least as strong as that between chromium and iron or aluminium.

The deficiency of chromium in the deep sea sediments may be explained in a similar way as for vanadium. The conditions in these regions are not favourable for the deposition of this element. More favourable conditions prevail on the shelf.

Manganese

The three ferrides hitherto discussed are abundant in the core sediment to an amount similar to that of shelf sediments (Ti) or they have decreased considerably (V, Cr), compared with the resistates or the hydrolyzates of the shelf. The amount of manganese, on the other hand, has increased appreciably in the deep sea sediments investigated.

The average content of Mn in igneous rocks is estimated at 1 000 ppm. The silicic rocks have a somewhat lower content than the subsilicic ones, but the difference in the content of manganese in the igneous rocks is rather small.

In the sediments manganese is abundant in hydrolyzates and precipitates but only traces of Mn are found in the resistates. The average content in the hydrolyzates is estimated at 620 ppm (MINAMI, 1935). This figure is cited by RANKAMA and SAHAMA (1950) and may be considered the most likely average value.

For reasons discussed later it is useless to make corrections of the manganese contents determined with regard to the aluminium content. Besides, a greater interest is due to the Mn/Fe ratio when dealing with the geochemistry of this element.

The distribution of manganese in the upper lithosphere should be fairly well known since Mn belongs to those minor constituents of rocks and sediments which become determined in the chemical analyses. Also in deep sea sediment some data of the content of manganese are available. However, the analytical data of this element must be regarded with care due to analytical errors. As to the deep sea sediments, estimates of the average content differ largerly and are of little interest.

A survey of the distribution of manganese and the ratio Mn/Fe in different milieus of interest is given below.

Igneous rocks	Mn (in ppm)	100 Mn/Fe
Gabbro	1160	1.77
diorite	700	1.52
granite	390	1.77
Average for igneous rocks	1000	2.03
Sediments:		
Hydrolyzates (average)	620	1.93
Tyrrhenian Sea (LANDERGREN, 1948)	1300	2.18
»Meteor» sediment (CORRENS, 1937)	1600	6.28
Red clay (CLARKE-STEIGER, 1924)	7670	11.4
Red clay (LANDERGREN, 1954)	9430	17.8
Core 238 (LANDERGREN)	2400	8.23
Sea water (RANKAMA-SAHAMA, 1950)	0.001—0.01	50—5

In Fig. 3 a diagram illustrates the distribution of manganese through the core. Of interest is to note some solitary maxima of the content (i. a. at 690, 790, and 1 270 cms from the top).

Several authors have dealt with the problem regarding the enrichment of manganese and the increase in the ratio Mn/Fe of the deposits on the ocean floor and opinions diverge considerably. It is not my intention to enter into this discussion with some few data from a single core from the Atlantic and some few observations from the Pacific. Only some general remarks to the discussion concerning the ratio Mn/Fe may be mentioned.

In the oxidates and the hydrolyzates on the shelf manganese and iron are precipitated in a ratio Mn/Fe regulated by the pH, the pressure of carbon dioxide and other conditions prevailing in the milieu. Under conditions mainly prevailing on the shelf iron is deposited more readily than manganese. A considerable part of Mn is carried to the oceans, and the ratio Mn/Fe in sea water is increased notably (5 to 50 units). Thus, it is reasonable that the ratio Mn/Fe in the deep sea deposits on the ocean floor will tend to assume values similar to those found in sea water in the minor cycle water-bottom sediment. Variations in the physico-chemical conditions in the bottom water of the oceans give rise to variations in the ratio Mn/Fe in the water and the sediments settled in the milieu. W. C. KRUMBEIN and R. M. GARRELS have recently paid attention to the importance of the redox potential and the pH conditions as regulating factors in the sedimentary processes in marine milieus (1952).

As seen from Table 5 the variations in the Mn/Fe ratio in the different parts of the core 238 are of the same magnitude as those of the other ferrides studied.

Iron has already been discussed in connection with the major constituents.

Cobalt

The average content of this element in igneous rocks is estimated at 23 ppm (SANDELL and GOLDICH, 1943). The earlier estimate by V. M. GOLDSCHMIDT is 40 ppm which may be a little too high. The content of this metal in the hydrolyzate sediments varies considerably as demonstrated by LUNDEGÅRDH (1946) and SAHAMA (1945). RANKAMA and SAHAMA have cited a content of Co in the hydrolyzates of 8 ppm on an average. In resistates and precipitates the amount of cobalt is negligible, as seen from Table 4. If the low content in the shelf sediments means that the vast part of this element is carried to the oceans, is an open question. In fact, several shelf sediments have contents of cobalt which are appreciable.

In the diagram of Fig. 3 the distribution of cobalt through the core is illustrated. Since the content of cobalt is rather low and in many cases below the limit of quantitative determination it is difficult to elucidate a closer relationship between iron and cobalt which one might have expected.

Nickel

The amount of this element in the igneous rocks varies considerably symbatically with the basicity of rocks, due to the close relationship between nickel and magnesium. SANDELL and GOLDICH give 80 ppm as an average for igneous rocks which seems to be reasonable. In the hydrolyzates is nickel but little abundant. The average content in the hydrolyzates is estimated at 24 ppm. Also in this case the question may be asked if the bulk of nickel — like cobalt — is carried to the oceans thus giving raise to the increasing content in the deep sea sediments. It should be borne in mind, however, that certain shelf sediments contain nickel to an amount similar to that of deep sea sediments. If the figures for nickel in the core are corrected with regard to aluminum we arrive at the following contents:

Level	ppm Ni (uncorr.)	ppm Ni (corrected)
10—320 cms	170	178
330—690 »	230	390
700—800 »	120	128
810—1411 »	60	162

The corrected average for the core is 240 ppm Ni.

As seen from Table 5 th ratio Ni/Fe varies notably in the different parts of the core. The variations are greater than those of the ratio Co/Fe. Also when regarding the diagram of the distribution of Ni through the core, as seen from Fig. 2, one finds that no obvious relationship between nickel and iron (Fig. 3) can be discovered. The relationship between nickel and magnesium, on the other hand, is well illustrated in Fig. 2. For further discussion of the relationship between nickel on the one hand and magnesium, iron, magnesium + iron, and cobalt on the other a survey of the ratios in question may be useful.

From the figures presented above it is likely to believe in a relationship between nickel and the other elements discussed. However, the ratio 100 Ni/(Mg + Fe) shows the smallest variations through the core. This indicates that the bulk of nickel enters structures of rock-forming minerals with iron and magnesium as major positive ions.

Level	100 Ni/Mg	100 Ni/Fe	100 Ni/(Mg + Fe)	Co/Ni
10—320 cms	0.81	0.42	0.28	0.20
330—690 »	0.64	0.59	0.32	0.14
700—800 »	0.80	0.38	0.26	0.26
810—1411 »	0.55	0.28	0.20	0.34
Average:	0.70	0.45	0.28	0.20

The ratio Co/Ni is of interest. If presuming that the two elements derive from the same source, viz. the same rock material, the ratio indicates that the minerogene component of the core sediment probably emanates from basic igneous rocks (cf. Table 5).

The Grain Size

As already mentioned O. MELLIS is studying the grain size of the core sediment by means of a method worked out by him. This method will be described in a forthcoming paper by MELLIS.

The percentage amount of grains with a size $>6\ \mu$ is determined in each sample of the core and the results are plotted in the diagram in Fig. 2. The samples spectrochemically analysed are parts of those of which the grain size have been determined. The two series of determinations were performed simultaneously but independantly of each other.

The diagram illustrating the grain size is of interest from different viewpoints. Thus, for example, the subdivision of the core into four parts on account of the distribution of the elements analysed, is significant also with regard to the distribution of grain size. I have intentionally put the diagram of the distribution of the grain size together with those of magnesium and nickel in Fig. 2. These diagrams illustrate fairly well the relationship between the three quantities grain size, magnesium, and nickel.

As seen from Figs. 1—3 the relationship between the quantities illustrated in the diagrams is more or less evident. It is, therefore of importance to find an expression for the relationship between the quantities dealt with in order to make comparisons possible when discussing the possible hypothesis concerned with the origin of the sediment investigated.

The Correlation Coefficients

Comparisons of diagrams of the distribution of elements may give an idea whether or not a marked co-variance or correlation between a single pair of elements exists. It is essential, however, when considering a relationship, to find a mathematical expression on which further discussions can be based. This is a matter of statistics and the method I have employed in this case has been to calculate the product-moment coefficients of correlation (the r-values). This method has been useful when discussing the distribution of elements (LANDERGREN, 1948). It ought to be emphasized, however, that the r-values should be used with due precaution since several factors affect the accuracy of the coefficients, i. a. the selection of samples to be correlated, the mumber of observations, deviations from a normal distribution of the variables etc.

A single pair of variables may be in a primary or secondary relationship to each other. Thus, for example, a marked positive correlation might be observed between, say grain size and nickel. There is also a notable positive correlation between magnesium and nickel (for crystal-chemical reasons) and between magnesium and grain size. Thus, the question might arise whether or not the first mentioned result is merely due to the correlation between grain size and magnesium. It is, therefore, essential for the discussion of possible hypothesis concerning the relationship between elements whether or not a correlation between a single pair of variables can or cannot be accounted for solely by observed correlation between each of these two variables and a third one. Problems of this type, in which it is necessary to consider simultaneously the relations between at least three variables may be treated by calculating the partial correlation coefficients of three variables whereby one of them is remaining constant. In order to ascertain if an observed correlation can be regarded as primary or secondary I have calculated some partial correlation coefficient which may be regarded as essential for the discussion.

In Table 6 the correlation coefficients are

presented. With the guidance of this Table the correlations will be discussed. The *grain size* is correlated with aluminium, magnesium, and the ferrides. The correlation coefficient (abbreviated r-value) for grain size and aluminium (abbreviated gs-Al) is -0.11. This low value of r indicates a rather feeble correlation between the two quantities. It should be born in mind that particle size and content of Al in a normal hydrolyzate are pronounced antibatic. This tendency is certainly indicated in the diagrams illustrating the distribution (Figs 1 and 2), but a fairly strong negative correlation between the two quantities might be expected if we had to deal with a normally deposited hydrolyzate.

The r-values for gs and the other quantities are of interest, especially those of gs-Mg, gs-Ni, and gs-Cr. A comparatively strong positive correlation exists between grain size and magnesium, as mentioned before. With decreasing numerical value of r follow those for gs-Ni and gs-Cr. If now the partial correlation coefficients are considered for the aforementioned pairs of variables, where magnesium is kept constant, we find that the r-values of the partial correlations grain size — nickel — (magnesium) (abbreviated gs-Ni-(Mg)) and gs-Cr-(Mg) are strongly affected so that the r-values even have become negative (which in this case has no real sense). On the other hand, when regarding the influence of (Fe), (Ti), (Mn), and (Ni) on the r-values for gs-Mg one finds that the effect is nil or — in the case of (Ni) — rather feeble. This feature is easily understood from a crystal-chemical viewpoint. Magnesium is a major mineral-forming constituent and can thus be put in a direct relationship to the particle size of the minerals of the sediment. Nickel and chromium on the other hand, are not mineral-forming constituents. They are entering structures of magnesium- and iron-bearing minerals and are consequently only indirectly correlated with the grain size.

The correlation between grain size and the other ferrides are weak, most of them tending towards zero. Of interest is to note the feeble correlation gs-Fe. This may be due to iron being a constituent also of other minerals than those in which magnesium enters.

The correlations between *magnesium* and the ferrides offer a considerable interest and ought to be discussed. The r-values for Mg-Ni and Mg-Cr indicate a strong positive correlation. Mg-Fe and Mg-V show a »medium» correlation and Mg-Co, Mg-Ti, and Mg-Mn are weak. In Table 7 is illustrated the decreasing relationship between magnesium and the ferrides in terms of correlation coefficients.

Of interest is the effect of (Fe) on the r-values of Mg correlated with the other ferrides. As seen from Table 6 the r-values of the fifth column are all affected by (Fe) but to different degrees. Considering the effect of (Fe) on the single-pair correlations one arrives at the following series with decreasing effect: Mn > Ti > V > Co > Cr > Ni. This series is almost inverse to that illustrating the correlation between Mg and the ferrides. The cause of this order of the partial correlation coefficients may be the following: Iron and mangesium are the two dominating mineral-forming elements. The minerogene component of the sediment consists of minerals with magnesium or iron as dominating positive ions. Those ferrides occurring as minor constituents are distributed due to their crystal-chemical properties. Consequently the elements nickel, chromium and — partly — cobalt enter structures of magnesium minerals and manganese, titanium, vanadium and partly cobalt preferably occur in iron-mineral structures. This arrangement of the ferrides is in agreement with the distribution-principle of the ferrides in the basic igneous rocks, suggesting that the minerogene component of the sediment, at least to a great extent, is derived from such igneous rocks.

The mutual relationship within the *ferride*

TABLE 6

A Survey of the Correlation Coefficients

Abbreviations: Variables within paranthesis means those regarded constant in the partial correlations. gs = grain size.

Correlations of single pairs of variables	Coefficients of partial correlations between three variables					
The variables	r:	(gs)	(Mg)	(Fe)	(Ti)	(Mn)	(Ni)
gs—Mg	+.67	—	—	+.68	+.68	+.68	+.58
—Ti	+.08	—	—.13	+.01	—	+.08	—.16
—V	+.12	—	—.21	+.06	+.09	+.12	—.23
—Cr	+.36	—	—.28	+.34	+.38	+.37	+.05
—Mn	+.01	—	—.15	—.09	—.01	—	—.19
—Fe	+.15	—	—.24	—	+.12	+.18	—.13
—Co	+.03	—	—.23	—.01	0	+.02	—.33
—Ni	+.45	—	—.20	+.45	+.46	+.48	—
Mg—Ti	+.26	+.28	—	+.06	—	+.23	—.23
—V	+.39	+.42	—	+.23	+.31	+.37	—.24
—Cr	+.74	+.72	—	+.65	+.74	+.74	+.39
—Mn	+.17	+.23	—	—.09	+.13	—	—.21
—Fe	+.46	+.49	—	—	+.40	+.44	+.04
—Co	+.29	+.36	—	+.19	+.21	+.26	—.37
—Ni	+.80	+.75	—	+.74	+.80	+.78	—
Ti—V	+.67	+.66	+.64	+.58	—	+.65	+.54
—Cr	+.55	+.56	+.56	+.38	—	+.53	+.35
—Mn	+.21	+.21	+.18	—.04	—	—	+.05
—Fe	+.46	+.45	+.40	—	—	+.42	+.30
—Co	+.37	+.37	+.31	+.28	—	+.34	+.13
—Ni	+.47	+.48	+.45	+.30	—	+.43	—
V—Cr	+.60	+.58	+.50	+.47	+.37	+.57	+.26
—Mn	+.17	+.17	+.11	—.08	+.04	—	—.08
—Fe	+.45	+.43	+.33	—	+.21	+.43	+.15
—Co	+.22	+.22	+.20	+.10	—.04	+.19	—.24
—Ni	+.63	+.65	+.58	+.51	+.47	+.62	—
Cr—Mn	+.26	+.29	+.20	—.12	+.17	—	0
—Fe	+.61	+.61	+.49	—	+.48	+.57	+.37
—Co	+.38	+.40	+.26	+.28	+.23	+.34	—.09
—Ni	+.73	+.68	+.35	+.59	+.64	+.71	—
Mn—Fe	+.52	+.53	+.50	—	+.48	—	+.41
—Co	+.24	+.24	+.20	+.11	+.18	—	+.04
—Ni	+.36	+.40	+.37	+.10	+.30	—	—
Fe—Co	+.28	+.28	+.18	—	+.13	+.18	—.06
—Ni	+.55	+.54	+.34	—	+.42	+.45	—
Co—Ni	+.59	+.65	+.63	+.55	+.51	+.55	—

group will now be discussed. The ferrides are, from a crystal-chemical point of view mineral forming elements or not. In this sediment titanium, iron, and manganese are the major constituents in the oxide minerals, occurring in some cases rather frequently (personal communication by Dr. MELLIS). Vanadium, chromium, cobalt and nickel occur as minor constituents. It is of interest to try to ascertain how the minor ferrides are distributed on the oxide-mineral structures. One method is to study the effect of the mineral-forming ferrides on the correlation coefficients. This is best demonstrated by some examples.

The r-value for V-Fe is + 0.45 (see Table 6), the partial correlation coefficient for V-Fe-(Ti) is + 0.21. The decreasing effect of titanium on the correlation between vanadium and iron is thus considerable. On the other hand, the r-value for V-Ti is + 0.67 and the partial r-value for V-Ti-(Fe) is + 0.58. The decreasing effect of Ti on the correlation V-Fe is stronger than that of Fe on the correlation V-Ti. From this I infer that vanadium more readily enters structures of titaniferous oxides (ilmenite, titanian magnetite). This result is in agreement with my own investigations on titaniferous iron ores (LANDERGREN, 1948) where vanadium is notably enriched.

Another examples: The correlation coefficient for Cr-Fe is + 0.61. The partial correlation Cr-Fe-(Ti) gives + 0.38. The corresponding figures for Cr-Ti and Cr-Ti-(Fe) are + 0.55 and + 0.38 respectively. Iron has a little stronger decreasing effect on the r-value in question than has titanium. Observation of the content of chromium from titaniferous iron ores, for example Smålands Taberg, shows that chromium is not abundant in the titanium-bearing magnetites. (LANDERGREN, 1948).

Employing this method for the other correlations between the ferrides I arrive at the following conclusion regarding the distribution of the minor ferrides on the major ones in this sediment:

Vanadium enters preferably structures of the titanium-bearing oxides. Cobalt and chrommium occur only in minute quantities.

In the oxides where titanium and manganese are minor constituents and iron the major one we find — apart from titanium and manganese — preferably chromium and nickel. Cobalt is present but in small amounts.

It should be emphasized that these conclusions are only tentative. Nevertheless, they are in good agreement with the general distribution principles for the ferrides, especially if the basic igneous rocks are considered.

Manganese behaves decidedly different compared with the other ferrides. As seen from Table 7 the correlation coefficients between quantities where Mn is one variable are low, in some cases approaching zero. The only r-value of importance is quite naturally that for Fe-Mn. The influence of (Mn) on the partial correlations is in most cases practically nil. One gets the impression that manganese on the whole is in a rather feeble relationship with the other ferrides, with magnesium, and with grain size. Hence one inclines to assume that the source of this ferride is to a great extent different from that of the other ferrides.

TABLE 7

Correlation Coefficient between single pairs of Variables arranged with decreasing numerical values

Grain size:							
Mg >	Ni >	Cr >	Fe >	V >	Ti >	Co >	Mn
.61	.45	.36	.15	.12	.08	.03	0
Magnesium:							
Ni >	Cr >	Fe >	V >	Co >	Ti >	Mn	
.80	.74	.46	.39	.29	.26	.17	
Titanium:							
V >	Cr >	Ni >	Fe >	Co >	Mn		
.67	.55	.47	.46	.37	.21		
Vanadium:							
Ti >	Ni >	Cr >	Fe >	Co >	Mn		
.67	.63	.60	.45	.22	.17		
Chromium:							
Ni >	Fe >	V >	Ti >	Co >	Mn		
.73	.61	.60	.55	.38	.26		
Manganese:							
Fe >	Ni >	Cr >	Co >	Ti >	V		
.52	.36	.26	.24	.21	.17		
Iron:							
Cr >	Ni >	Mn >	Ti >	V >	Co		
.61	.55	.52	.46	.45	.28		
Cobalt:							
Ni >	Cr >	Ti >	Fe >	Mn >	V		
.59	.38	.37	.28	.24	.22		
Nickel:							
Cr >	V >	Co >	Fe >	Ti >	Mn		
.73	.63	.59	.55	.47	.36		

As mentioned before the source of manganese in the deep-sea sediments has been much discussed in literature and many hypothesis have been put forward. Three general views on the problem are worthy of discussion. C. CORRENS (1941) has suggested that a biological extraction from sea water is responsible for the accumulation of manganese in deep sea deposits. The element is settled in the calcareous shells of foraminifera and replaces calcium diadochically in the calcite structure of shells.

P. H. KUENEN (1941) has asserted that a chemical precipitation from the sea water accounts for the high content of manganese in the deep sea sediments. In fact, the ratio Mn/Fe in deep sea sediments is of the same magnitude as that of sea water, but the discussion is essentially concerned with the question if the quantity of manganese in sea water is sufficient for the accumulation of the element in the deep sea deposits.

According to H. PETTERSSON (1945) the adsorbtion of manganese on volcanic dust is more important than its biological or its inorganic precipitation. He emphasizes that the deep sea manganese cannot be solely derived from sea water and advocates that submarine volcanic eruptions form the main source of manganese deposited on the ocean floor, and the element is released by submarine weathering activated by the occurrence of hydrochloric acid which may dissolve more manganese than iron from the submarine lavas.

The present study on a single sediment core can but little contribute to the discussion concerning the source of manganese in the deep sea sediments. Only a few remarks will be added. The aforementioned feeble correlation between manganese and the other quantities investigated is in agreement with the conception that the main source of manganese may be different from that of the other elements significant for a hydrolyzate deriving from basic igneous rocks.

Manganese is settled in the deep sea sediment in a ratio Mn/Fe similar to that of sea water. The feeble relationship between manganese and the other ferrides (with exception of iron!) indicates that Mn is involved in the exchange between bottom water and bottom sediment to a greater extent than are the other ones. In this system manganese is precipitated together with iron in a ratio regulated by the water conditions (pH, redox potential etc.). If the increase of manganese is regarded from this viewpoint a discussion of the primary source of this metal in the deep sea deposits seems inessential.

Some Remarks as to the relative Rate of Accumulation of Ca, Al, Ti, and Mn

The correlation coefficient Al-Ti is found to be $+ 0.68$. This indicates a marked relationship between the two elements. However, the distribution of Al in the core is not normal as is seen from the diagram in Fig. 1. The distribution of titanium, too, is rather irregular. On the other hand, the diagrams of the distribution of the elements indicate that they are symbatic. The question may therefore be asked whether the correlation coefficient calculated is significant or not. The relationship in question is of geochemical interest. In a comprehensive work on the deep-sea sediments of the Pacific by G. ARRHENIUS (1953) the author has used the content of titanium as a measure of the lutite concentration instead of aluminium which from a theoretical point of view is the foremost one. According to WISEMAN and OVEY (1950), the use of titanium in this connection should mean an advantage. This, however, seems remote to the present author. Anyhow, it is of interest to see if Arrhenius' presumption is valid also for the sediment of core 238.

If now the significance of the correlation coefficient Al-Ti is doubtful the relationship existing can be illustrated in a diagram show-

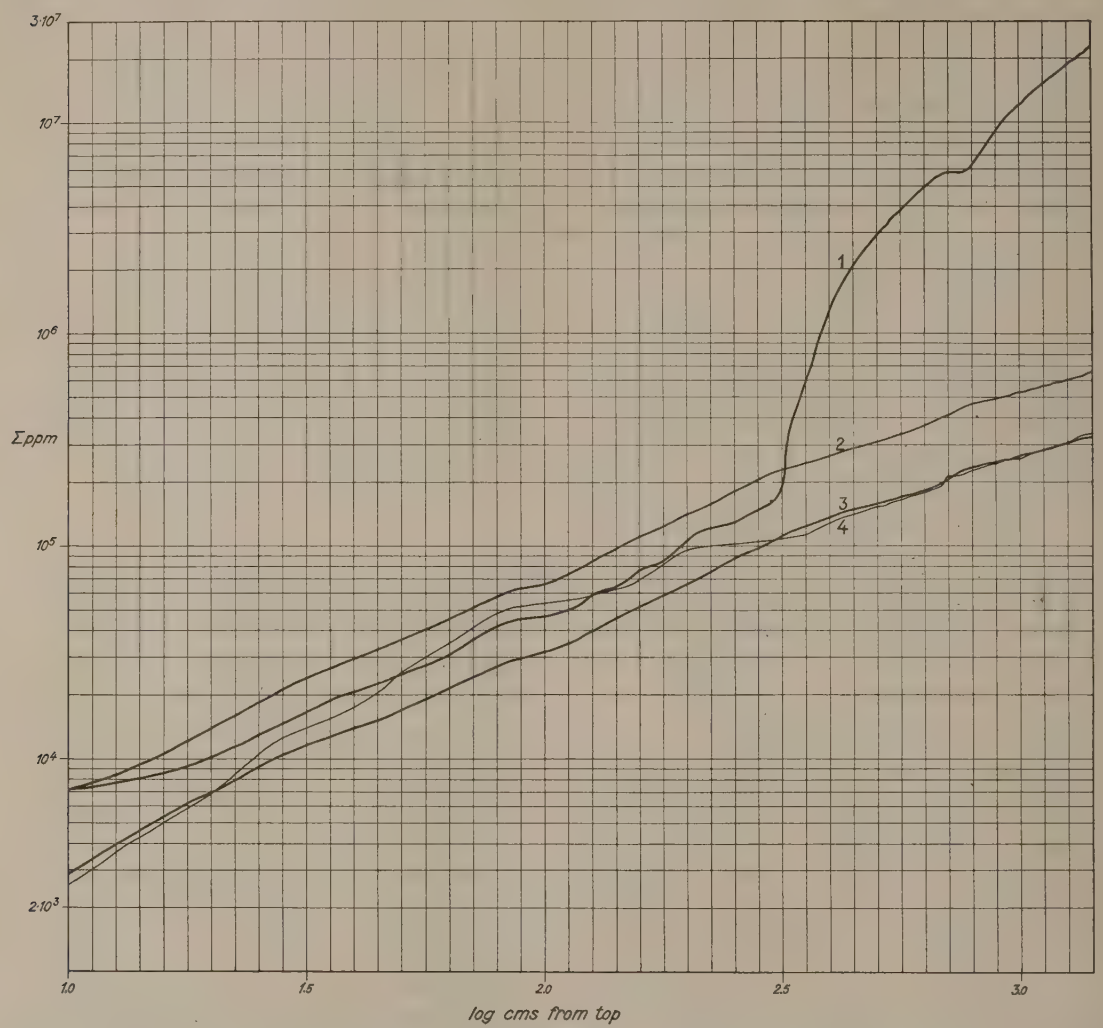

Fig. 4. Diagram illustrating the relative rate of accumulation of calcium (1), aluminium (2), titanium (3), and manganese (4) in the core 238. The abscissa is the length of the core in log cms from the top. The ordinate represents the successive accumulation of the elements through the core in ppm on a logarithmic scale.

ing the relative rate of accumulation of the elements. The diagrams in Fig. 4 illustrate this in a simplified way. The abscissa represents the length of the core in log cms from the top. The ordinate represents the successive accumulation of the contents of calcium (1), aluminium (2), titanium (3), and manganese (4). The contents are in ppm. If the rate of accumulation of an element in such a simplified diagram is quite uniform through the core the coordinates fall on a straight line. Deviations from the straight line indicate of course variations in the rate of accumulation. Two elements have a similar rate of accumulation if their curves in the diagram are uniform.

As seen from Fig. 4 the curves of Al and Ti are quite uniform indicating a close similarity in the rate of accumulation. This must also indicate a close relationship between Al and Ti so that any of them may be used as measure of the concentration of lutite, as suggested by Arrhenius.

The curve for calcium demonstrates the changes in the rate of accumulation due to the varying supply of calcite intensified in the lower part of the core. Manganese behaves

a little different compared with Al and Ti. Only in the lowest part of the core the curves of manganese and titanium are similar.

On the relative Abundance of the stable Carbon Isotopes

NIER and GULBRANSEN (1939) have stated that the ratio $^{12}C/^{13}C$ is higher in carbon of organic origin than in that derived from carbonate. As the accuracy of the mass spectrometric measurements has increased also slighter variations in the isotope ratio can be discussed from different points of view. In a recent investigation (LANDERGREN, 1954) the ratio $^{12}C/^{13}C$ has been determined in about 200 samples of marine sediments settled under different geological conditions. It is suggested that variations in the relative abundance of the stable carbon isotopes in calcite are due to the geological conditions prevailing during the formation of the sediments. Thus, the magnitude of the ratio $^{12}C/^{13}C$ is dependent on to what extent carbon derived from organic processes is involved in the carbon dioxide cycle developed in the milieu of precipitation of calcite. In stagnant water, for example, the amount of the lighter isotope increases in the calcite deposited due to the intensity of the exchange carbonate-bicarbonate where a comparatively large amount of carbon derived from organic processes takes part. In agitated water, on the other hand, where the conditions are unfavourable for the development of a local carbon dioxide cycle the content of the lighter isotope decreases and the ratio $^{12}C/^{13}C$ tends to assume a value significant for an open marine milieu.

Some figures from the investigation mentioned may illustrate the difference in the isotope ratio due to differences in the milieu.

Calcite settled in open marine milieu has an isotope ratio of 88.5—88.6. Calcite formed in basins with restricted communication with the open sea has a ratio of 89.0—89.9.

The ratio has been determined in samples taken from core 238. The results are presented below.

Level	$^{12}C/^{13}C$ in calcite
460 — 461.5	88.67
580 — 581.5	88.74
660 — 661.5	88.75
819.5— 821	88.72
1050 —1051.5	88.80
1140 —1141.5	88.79
1310 —1311.5	88.74

The ratio is rather similar in the samples. The average is 88.74 and thus higher than that significant for an open marine milieu. It is similar to the ratio determined in shelf sediments formed under more quiet water conditions than those prevailing in an open marine milieu. It is likely that the water conditions in the bottom water of an isolated deep are more quiet and undisturbed than those of marine surface water thus giving raise to a slight increase in the amount of the lighter isotope, viz. increase in the ratio $^{12}C/^{13}C$ as observed in the calcite of the core 238 sediment.

A comparison between the isotope ratio of the core sediment and that found in the minute calcite component of the red clay of the Pacific is of interest. The calcite of the red clay has an isotope ratio of 89.49 on an average. This value is rather high and comparable with that observed in shelf sediments formed in restricted basins, for example alum shales. This seems to indicate that the calcite of the red clay is deposited under very quiet water conditions so that a local carbon dioxide cycle has become developed in which a considerable part of the organic carbon has been involved. The difference in the water conditions between the two deep sea milieus discussed is obvious, if the carbon isotope ratio is considered. The conclusion regarding the water conditions are in good agreement with observations by F. KOCZY (1953).

General Conclusions and Summary

Clearly, conclusions drawn from the distribution of elements observed in samples from a single sediment core must be limited, even if the length of the core and the number of analyses are considered. Nevertheless, the good deal of work bestowed on a single core of a sediment settled under — often incorrectly called — »special» conditions has not been in vain from a geochemical point of view. Besides, the results may also be looked upon as an introduction of geochemical methods intended for further studies on the geochemistry of the deep sea sediments.

The contents of the *major constituents* aluminium, magnesium, calcium, and iron are presented in Tables 1 and 2 (iron). The distribution is illustrated in the diagrams of Figs. 1—3. The distribution of the major constituents gives rise to a subdivision of the core samples into four parts, each showing specific features with regard to the distribution of elements.

The content of aluminium is a measure of the amount of hydrolyzate occurring in the sediment. Since the bulk of the elements analysed are bound in the hydrolyzate component, corrections of the amounts of other elements are made with regard to the content of aluminium. The corrected figures are presented in connection with the descriptions of the single elements.

Magnesium is not very abundant in a normal hydrolyzate. The somewhat increased content of this element indicates the abundance of dark rock-minerals mainly emanating from basic igneous rocks, since the positive correlation between magnesium and nickel-chromium is rather strong.

Calcium is a measure of the amount of of calcite derived from organic matter, especially from shells of formaninifera. These animals are very irregularly distributed in the core and most frequent in the lowest part.

Iron is the major *ferride metal* and major constituent (together with titanium and manganese) in the oxide minerals distributed in the sediment. The contents of the other ferrides are recalculated with iron as reference element (Table 5). The contents of the ferrides in the samples are presented in Table 3. The distribution of titanium, manganese, iron, cobalt, and nickel is illustrated in the diagrams of Figs. 1—3. These diagrams gives also an idea of the relationship that exists between the ferrides mentioned on the one hand and grain size, magnesium, and aluminium on the other.

The average contents of the elements analysed in the different parts of the core together with those from other sources are presented in Tables 2, 4, and 5.

The *correlation coefficients* are measures of the mutual relationship between the quantities dealt with. Tables 6 and 7 contain surveys of the correlation coefficients calculated. The relationship between grain size and magnesium shows that the magnesium minerals preferably occur in the coarser classes of grain size. This is a remarkable feature giving information as to the source of the sediments. The correlation between magnesium and the ferrides is of interest — especially that between Mg and the ferrides Cr and Ni — since the primary relationship between these elements in the basic igneous rocks, the probable source of the sediment, is maintained in the hydrolyzate component. Also the correlations within the ferrides show that the relative abundance of these elements are similar to that in basic igneous rocks and in correspondence with conception by V. M. GOLDSCHMIDT concerning the distribution principles of elements in the igenous rocks.

As to the *source of the hydrolyzate component* in the core sediment two alternatives may be considered. The first alternative is that the hydrolyzate emanates from weathering material of terrestrial igneous rocks. According

to O. MELLIS who has studied the mineral composition of the core sediment (personal communication) quartz is present in minute quantities only. The vast majority of minerals are magnesium-iron bearing silicates or hydrosilicates (pyroxene, amphibole, olivine, serpentine etc.), basic plagioclase, and ore minerals. This mineral composition corresponds fairly well with the conclusion from geochemical premises, namely, that the source material probably derives from basic igneous rocks.

Clearly, the material might emanate exclusively from weathering material of terrestrial basic igneous rocks. However, studying a geological map of Africa and the distribution of silicic and subsilicic igneous rocks within this region leads to the conclusion, that a hydrolyzate emanating from the rocks of this region with a chemical composition similar to that of the core sediment is exceedingly unlikely. Local influence on the chemical composition of a near-shore sediment may occur, due to the effect from ores or igneous rocks with anomal chemical composition but such phenomena are inessential for the dicussion.

The second alternative — and the most likely one — is that the hydrolyzate component of the sediment mainly derives from the submarine rocks in the surroundings of the deep here dealt with.

According to O. MELLIS (personal communication) the submarine weathering can become considerable and must be taken into account when discussing the source material of deep sea sediments. Starting from the geochemical data presented in this study I arrive at the conclusion, that the source material of the hydrolyzate component of the sediment mainly derives from the basic igneous rocks occurring in the surroundings of the deep from which the core was raised.

The *source of manganese*, finally, has been discussed before and should only be briefly mentioned. Due to the feeble relationship between this ferride and the other elements dealt with the conclusion is drawn, that the source of this element is different from that of the other ferrides. The correlation between manganese and grain size is zero indicating that the settling of this metal runs independantly of the other ferrides. Manganese is deposited in a ratio Mn/Fe similar to that in sea water and due to the conditions of the bottom water (pH, redox potential, pressure of carbon dioxide etc). The primary source may then be organic or volcanic but the amount of the element settled and the ratio Mn/Fe is strongly regulated by the conditions mentioned.

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